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Energy-related GHG emissions balances: IPCC versus LCA

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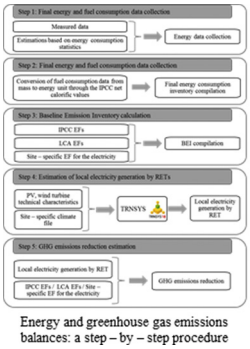
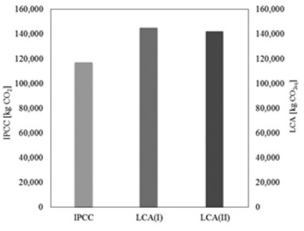
HIGHLIGHTS

- Estimate of the GHG balance of a small city through the IPCC and the LCA approach
- Estimate of a site – specific LCA GHG emission factor for electricity consumption
- The compilation of a local GHG balance could suffer from the lack of information.
- The GHG emission obtained with the LCA is higher than 20% respect to the IPCC.
- The LCA could be more suitable in matching local and global GHG reduction goals.

GRAPHICAL ABSTRACT


Step 1: Final energy and fuel consumption data collection
Measured data
Estimations based on energy consumption statistics
Energy data collection
Step 2: Final energy and fuel consumption data collection
Conversion of fuel consumption data from mass to energy unit through the IPCC net calorific values
Final energy consumption inventory compilation
Step 3: Baseline Emission Inventory calculation
IPCC EFs
LCA EFs
Site – specific EF for the electricity
BEI compilation
Step 4: Estimation of local electricity generation by RETs
PV, wind turbine technical characteristics
Site – specific climate file
TRNSYS
Local electricity generation by RET
Step 5: GHG emissions reduction estimation
Local electricity generation by RET
IPCC EFs / LCA EFs / Site – specific EF for the electricity
GHG emissions reduction

Energy and greenhouse gas emissions balances: a step – by – step procedure



Greenhouse gas emissions per capita (IPCC/LCA approach)

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ABSTRACT

Addressing climate change is **one** of the greatest environmental challenges. Due to the impact of cities to energy consumption, the involvement of the local authorities in environmental policies is rapidly increasing. The Covenant of Mayors (CoM), launched by the European Commission, is an urban initiative aimed at reducing CO_2 emissions. The signatories have to compile the greenhouse gas emissions (GHG) balance of their territory and, to do so, they can use the Intergovernmental Panel on Climate Change (IPCC) or the Life Cycle Assessment (LCA). Moreover, the signatories have to define strategies to reduce the GHG emissions.

In this context, authors estimate the GHG balance of an Italian municipality using both methodologies in order to compare the results. In detail, the first application is the IPCC, the second one is the LCA approach for which two cases are analysed: i) LCA with fossil fuels and electricity GHG emission factors based on the European Reference Life Cycle Database, LCA (I); and ii) LCA with a site – specific GHG emissions for electricity generation, LCA (II). They propose energy strategies in order to quantify the achievable GHG emissions reduction by the exploitation of the renewable energy resources. The study shows that the GHG emissions results obtained with the LCA approach are higher by 20% than those calculated with the IPCC approach. This difference is relevant and it could be significant in identifying effective climate strategies. The LCA methodology ensures a systemic accounting of emissions, then, it can be more effective in order to achieve GHG emissions reduction at global level. The examined energy strategies allow for reducing the GHG emissions of about 7% of the total reduction required by the CoM. This confirms that a preliminary evaluation of the strategies is useful for the allocation of the financial resources to the environmental policies.

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Nomenclature

BEI	Baseline Emission Inventory
COP	Conference of Parties
EF	Emission Factor
ETS	Emission Trading Scheme
EEA	European Environment Agency
ELCD	European Reference Life Cycle Database
EU	European Union
GWP	Global Warming Potential
GHG	Greenhouse Gas
IPCC	Integrated Panel on Climate Change
IEA	International Energy Agency
ISTAT	Italian National Statistical Institute
LCA	Life Cycle Assessment
LPG	Liquefied Petroleum Gas
RES	Renewable Energy Source
RET	Renewable Energy Technology
SEAP	Sustainable Energy Action Plan
SECAP	Sustainable Energy and Climate Action Plan

1. Introduction

On November 4th, 2016, the Conference of Parties (COP) 21 Agreement on climate change entered into force with the aims to hold the increase in the global average temperature below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C (UNFCCC, 2015).

In this context, it is of paramount importance to identify the main sources of the GHG emissions in order to put in place effective actions to tackle the climate change (Cellura et al., 2013b). Cities consume most of the energy produced to meet transport, commercial and industrial activities, heating and cooling demands and, in 2013, accounted for about two-thirds of primary energy demand and 70% of total energy-related CO_2 emissions (IEA, 2016a). Hence, efforts aimed at fostering sustainable urban energy paths are crucial to meet global low-carbon ambitions (Cellura et al., 2013a; IEA, 2016b). Local authorities are major players in climate policies due to their direct and indirect influence on GHG (Beccali et al., 2007; Bulkeley and Betsill, 2003; Dodman, 2009; Hoornweg et al., 2012, 2011, Kennedy et al., 2011, 2009; Pablo-Romero et al., 2015).

One of the most recent initiatives involving local authorities in the reduction of the GHG emissions is the Covenant of Mayors (CoM), launched in January 2008 by European Commission (2010) and updated in October 2015 (CoM, 2017). Signatories of the CoM have committed to prepare the Baseline Emission Inventory (BEI), i.e. the inventory of the GHG emissions that occur in their municipality. The BEI is the baseline for the identification of the energy strategies to reduce the GHG emissions. Both the BEI and the energy strategies are part of a document called Sustainable Energy Action Plan (SEAP). The signatories may decide to account the emissions in BEI using either the standard of the IPCC (2006) or the LCA approach (ISO, 2006a, 2006b). The proposed approaches use different system boundaries: the first one includes only the activities that occur within the municipality territories, the second one includes also the upstream and the downstream supply chains related to the in-boundary activities. The different approaches applied to the same system give different GHG balances.

In the above context, authors compiled the energy balance and the BEI of a small city in Sicily (Italy) and estimated the local electricity production from renewable energy technologies (RET) in order to evaluate the related GHG emissions reduction. They apply both the LCA and the IPCC approaches in compiling the BEI and in evaluating the GHG emissions reduction in order to highlight the differences in the obtained results. In addition, as the electricity sector is expected to play a key role in the future energy system, a more in depth analysis is carried out on the assessment of the GHG emissions related to this energy carrier.

In detail, the approaches proposed are:

1. IPCC - GHG (emission factors) EFs for fossil fuels and electricity consumption based on the standard of the IPCC (IPCC, 2006);

2a. LCA (I) – GHG EFs for fossil fuels and electricity consumption based on the European Reference Life Cycle Database (ELCD) (Wolf et al., 2008);

2b. LCA (II) – GHG EFs for fossil fuels based on the ELCD, and on site – specific data for electricity consumption.

This paper presents one of the first studies aimed at comparing the LCA and the IPCC approaches applied for the GHG emissions balance at local level. In fact, as described in Section 2, among seven studies on GHG emissions (D'Avignon et al., 2010; Kennedy et al., 2010; Marinakis et al., 2015; Matak et al., 2016; Nuss-Girona et al., 2016; Ridolfi et al., 2008; Yu et al., 2012), found in the scientific literature, only two use both approaches (Kennedy et al., 2010; Marinakis et al., 2015). However, in both papers the differences in the obtained results are not highlighted.

In addition, it highlights how the use of site – specific EF instead of average EF for the electricity can affect the obtained results, providing an indication on when it is appropriate to use a site-specific factor. Moreover, it provides useful information for the development of GHGs balance in future energy systems characterized by a higher level of penetration of electricity in the final energy use, and a methodology to fill the data gap about the specific primary data on energy consumption.

Data and results of this study can support municipality authorities involved in the CoM in the choice of the most effective approach for compiling the GHG inventory in order to match both local and global GHG reductions targets.

Finally, the study allows to highlight the "hot spot" sectors in terms of final energy consumption and GHG emissions. The analysis of the proposed energy strategies can provide useful information for the definition of energy and environmental strategies in municipalities with climatic and economic characteristics similar to the examined one.

2. IPCC versus LCA: main differences of the two approaches

In order to compile the GHG inventory of a municipality a data collection on the local energy consumption and production in each sector is needed.

As previously stated, the signatories may decide to account the emissions in the BEI using the IPCC standard or the LCA approaches.

The main differences of the two approaches are:

- the system boundaries selected for the calculation of the EFs of each energy carrier, i.e. only the use phase or the whole life cycle;
- the GHGs included in the calculation of the GHGs balance, i.e. only the CO_2 emissions or also the non-CO_2 GHG emissions, like N_2O, CH_4, etc.

With regard to the first aspect, the IPCC approach covers all the GHG emissions due to the energy consumption either directly due to fuel combustion or indirectly via fuel combustion associated with electricity and heat/cold generation within their territory. Then, the GHG emissions related to the use of biomass/biofuels, as well as the emissions from the electricity generated by using renewable energy sources (RES) are considered null, as they do not have GHG emissions related to the use phase. This entails an underestimation of the GHG emissions as in these cases the GHG emissions related to the upstream (supply chain and manufacturing) and downstream processes (following the use stage and end-of-life value chain) could have a non-negligible contribution to the overall emissions.

The LCA (ISO, 2006a, 2006b) approach computes the GHG emissions associated to the energy consumption considering the whole supply chain of each energy carrier. In detail, the LCA EFs include not only the emissions of the final combustion within the spatial boundary of a territory, but also all emissions of the upstream and downstream supply chain, i.e. emissions from exploitation, transport and processing (e.g. refinery) steps in addition to the final combustion. This approach includes also the emissions that take place outside the boundaries of the location the fuel is used in. Moreover, the GHG emissions caused by the use of biomass/biofuels and the emissions from the electricity generated by using RES are higher than zero.

With reference to the second aspect, in the SEAP guidelines (Bertoldi et al., 2010), the given IPCC EFs cover only the CO_2 emissions due to energy consumption. The emissions of CH_4 and N_2O are not included, as CO_2 is considered as the most important GHG. The standard EFs are based on the carbon content of each fuel. Optionally, the signatories can choose also to report the emissions of CH_4 and N_2O, converted into CO_{2eq} according to their global warming potential (GWP). In the LCA approach, the CO_2 and all the non-CO_2 GHGs, converted in CO_{2eq}, are taken into account in the assessment of the GHG emissions.

3. State-of-the-art

Several studies assessing the GHG emissions are available in literature. Local GHG inventories have been carried out in many city of the world with different goals (D'Avignon et al., 2010), some of these, carried out at a city or municipality scale, are briefly examined in the following paragraphs.

Ridolfi et al. (2008) applied the IPCC guidelines (IPCC, 1997) to estimate the emissions due to human activity in the Province of Siena (Italy). The authors, due to a lack of data, performed the analysis considering four of the six categories indicated by the IPCC: energy consumption, agriculture, land use change and forestry, and waste. For the energy sector, they estimated the CO_2 emissions due to the electricity use and to the fossil fuels combustion. For the agriculture sector, authors considered the CH_4 and N_2O emissions related to enteric fermentation and manure management of livestock and to fertilizer use. With regards to land use and forestry, they estimated natural uptake according to forest area; the GHG emissions from waste is based on CH_4 emissions during the decomposition of the organic fraction. All the non-CO_2 GHG emissions were transformed into CO_{2eq} using GWP.

D'Avignon et al. (2010) developed the local GHG emissions inventories of two Brazilian cities: Rio de Janeiro and São Paulo. Authors applied the Revised 1996 guidelines for National GHG Inventories (IPCC, 1997) adapted to local specificities and assessed the CO_2 and CH_4 emissions related to energy, changes in land use, agriculture and waste sector in both cities. They used two different criteria in evaluating the GHG emissions. In the first one, used for Rio de Janeiro, they developed the GHG inventory by applying the concept of the responsibility for emissions caused by the city, whether or not they occurred within the city. In the second one, used for São Paulo, the criterion was the use of the political and administrative boundaries, in other words they considered only the GHG emissions produced inside the geographic borders of the city. However, D'Avignon et al. presented the results only in terms of share of emissions by sector and by fuel type without illustrating the differences related to the use of the two different approaches.

Kennedy et al. (2010) used three different approaches for assessing GHG emissions (CO_{2eq}) related to cities. The first one includes only the emissions that are produced within the city boundaries; the second one includes also out-of-boundary emissions due to the electricity used in cities; in the third one, further out-of-boundary emissions attributable to cities are included, i.e. upstream emissions from fuel combustion (LCA perspective). Authors estimated the GHG emissions from landfill waste and of the direct emissions using a simplified version of the IPCC method and the default IPCC (2006) EFs for fuels, respectively. Although Kennedy et al. described the three approaches as usable for attributing GHG to cities, they did not publish the obtained results and their analysis.

Yu et al. (2012) employed a methodology, based on CoM, with the aim to estimate the CO_2 emissions of four Chinese cities. Due to the absence of country-specific EFs, they used the standard IPCC EFs for most energy carriers, except for electricity and heat. The EF for electricity was calculated considering the variation in the energy sources used for electricity generation.

Marinakis et al. (2015)) applied both the IPCC and the LCA methods in order to calculate the CO_2 emissions in a Greek municipality of the district of Peloponnese. The conversion of energy data to amount of CO_2 emission was done considering the factor proposed by the CoM (Bertoldi et al., 2010) for the IPCC and the LCA methods. Moreover, authors defined a number of factors for the LCA method considering specific features of the region. However, Marinakis et al. did not provide clear information about the definition of the specific EFs and in the paper, they did not carry out a comparative analysis of the obtained results as they focused mainly on the assessment of effectiveness of planned actions by using the three different approaches.

Nuss-Girona et al. (2016) developed the SEAP for the city of Girona (Catalonia, Spain). Authors compiled the baseline CO_{2eq} emissions inventory using the IPCC standard.

Matak et al. (2016) showed the methodology to calculate the BEI in the context of the development of the SEAP of the Croatian island of Korkula, in 2012. Authors estimated the energy consumption and compiled the baseline CO_2 emissions inventory in compliance with the standards of the IPCC.

The examined studies show that there is not a consensus on how to carry out a GHG emissions balance, as in literature both IPCC and LCA approaches are used and the emissions inventories are compiled considering in some cases only CO_2 emissions and in others all the GHG emissions. In detail, five of the seven analysed studies use the IPCC approach while the other two use both the IPCC and the LCA approach. Moreover, three studies report only the CO_2 emissions, one the CO_2 and the CH_4 emissions, and the three all GHG emissions.

As a conclusive remark, as stated in Cerutti et al. (2013), it is worth mentioning that among all accepted SEAPs, up to March 14th, 2013, in most cases (97.7%) the IPCC standard is used in the determination of the GHG balance. With regard to the emission inventory, 63.1% are reported in tonnes (t) CO_{2eq} and 36.9% in t CO_2.

4. Case study

In this section, authors describe the case study and compile the BEI. In detail, Section 4.1 provides a brief description of the examined municipality; Section 4.2 describes the final energy and fuel consumptions data collection, the BEI compilation and two energy strategies aimed at reducing the GHG emissions.

4.1. The examined municipality

The examined municipality is Licata a small town located in Sicily (Italy), in the Province of Agrigento (Fig. 1).

The Licata territory covers an area of 179.68 km^2 along the southern coast of Sicily. The climate is typical of the Mediterranean area, characterized by low annual precipitation, concentrated in the autumn and winter months. The winter is mild and rarely reaches temperatures below +5 °C; summer is very hot and humid. Licata's climate is classified in zone B (number of heating degree-days is 604 h) by the climatic classification introduced by the Italian Decree n. 412, 1993 as subsequently amended and supplemented (Decree of the President of the Republic, 1993), and as Csa (warm temperate climate with hot and dry summer) by the Köppen-Geiger climate classification system (Kottek et al., 2006).

The population trend of Licata is inferred from Italian National Statistical Institute (ISTAT) (Fig. 2) (ISTAT, 2017). In the last 10 years, the population decrease of about 4%.

Fig. 3 shows the number of enterprises for sector of activity based on the last survey by ISTAT in 2011 (ISTAT, 2017).

The number of enterprises in Licata was equal to 1863 in 2011. The largest share was represented by the "wholesale and retail trade; repair of motor vehicles, motorcycles" category (40%). The "accommodation and food service activities", "professional, scientific and technical activity" and "manufacturing activities" followed with percentage contributions equal to 11%, 9% and 8.7%, respectively. The agriculture, forestry and fishery sector represented 3% of the total enterprises. With reference to the agriculture sector utilised agricultural area accounted (UAA) for 90% of the total land area of Licata in 2011. Arable land (which includes land for cereals and other arable land) accounted for 76% of the UAA (ISTAT, 2017). Table 1 shows the total land area classified by use.

The industrial sector is almost absent and is characterized by olive oil production companies, fish conservation and shipbuilding.

4.2. Energy and GHG balances: a step-by-step procedure

In this paper, authors, starting from the data collection on the final energy consumption, calculate the energy balance of the municipality of Licata and the GHG emissions inventory using both the IPCC and the LCA methodologies. Moreover, they estimate the environmental benefits achievable with the implementation of two energy strategies.

The followed procedure can be recapped in five steps:

- Step 1 – Final energy and fuel consumption data collection: the final energy and fuel consumptions in each sector are taken from local data, when possible. When such data is not available, they are estimated from national/regional energy consumption statistics.
- Step 2 - Final energy consumptions inventory: in this step, authors compile and calculate the energy balance. Fuel consumption data is converted from mass to energy units through the net calorific values provided by IPCC (2006).
- Step 3 - BEI calculation: the BEI is assessed using both the IPCC and the LCA approaches. In detail, in the first application the standard EFs of the IPCC are used. In the second one the LCA EFs are used and two cases are analysed: i) LCA (I) with fossil fuels and electricity GHG EFs based on the ELCD; and ii) LCA (II) with a site – specific GHG emissions for the electricity generation.
- Step 4 – Estimation of the local electricity production by RET: in this step, authors estimate the electricity generation related to the installation of wind and photovoltaic power plants by using dynamic simulation tools;
- Step 5 – GHG emissions reduction estimation: estimation of the GHG emissions reduction achievable with the climate strategies analysed in Step 4 by the IPCC, LCA (I) and LCA (II) approaches.

Fig. 4 shows the step-by-step procedure.

4.2.1. First step: final energy and fuel consumptions data collection

Data on final energy and fuel consumptions are collected and/or estimated from a wide range of sources. The baseline year chosen for the energy inventory is 2010, as it is the year for which the most comprehensive and reliable data are available.

The sectors to be included in the BEI, as indicated in the SEAP guideline, are the following: municipal buildings, equipment/facilities; tertiary (non-municipal) buildings, equipment/facilities; residential buildings; public lighting; industries (excluding industries involved in the EU Emission trading scheme – ETS); municipal fleet; public transport; and private and commercial transport.

The final energy and fuel consumptions related to municipal building, equipment/facilities and tertiary (non-municipal) buildings, equipment/facilities, public lighting, public and municipal transport and agriculture sectors are obtained from local sources (Ortega, 2012),

Fig. 1. Case study – Licata municipality.

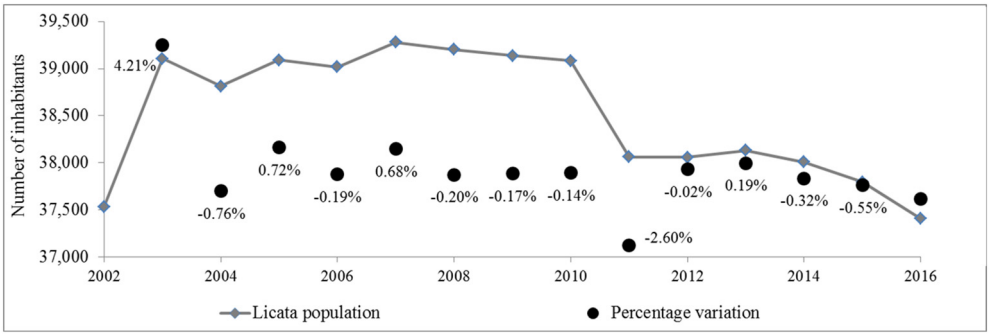


Fig. 2. Licata population trend 2002–2016 (ISTAT, 2017).

while the final energy and fuel consumptions related to the residential buildings and private and commercial transport sectors are estimated based on energy statistics.

A detailed description of each sector and the data sources are shown in Table 2, while the following section describes in detail the final energy consumption estimation for residential buildings and private and commercial transport.

4.2.1.1. Residential buildings. This sector includes all the final energy consumptions from residential buildings. The energy carriers considered are electricity and natural gas. Electricity consumption is estimated by using statistic regional energy consumption indicators published by ISTAT, providing data related to the per capita electricity consumption in 2010 with a sub-regional detail. In this case study, data referred to the Province of Agrigento are multiplied by the number of inhabitants to obtain the overall electricity consumption in the residential sector.

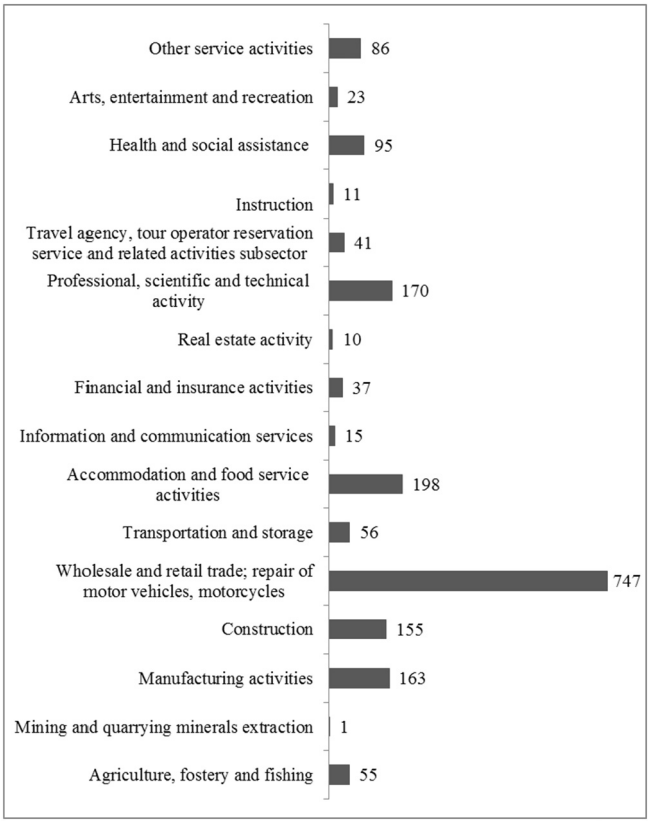

Other service activities 86
Arts, entertainment and recreation 23
Health and social assistance 95
Instruction 11
Travel agency, tour operator reservation service and related activities subsector 41
Professional, scientific and technical activity 170
Real estate activity 10
Financial and insurance activities 37
Information and communication services 15
Accommodation and food service activities 198
Transportation and storage 56
Wholesale and retail trade; repair of motor vehicles, motorcycles 747
Construction 155
Manufacturing activities 163
Mining and quarrying minerals extraction 1
Agriculture, fostery and fishing 55

Fig. 3. Number of enterprises for sector of activity (ISTAT, 2017).

4.2.1.2. Transportation. The Transportation sector includes all road transportation on the street network that is in the competence of the local authority (Bertoldi et al., 2010). In detail, it includes: 1 – energy consumption from municipal fleet i.e. from vehicles owned and used by the local authority's administration; 2 – public transport, i.e. energy consumption from buses, tramway, metro, urban rail transportation and local ferries used for passenger transport; and 3 – private and commercial transportation, i.e. energy consumption from road, rail and boat transport in the local authority's territory which refer to the transport of people and goods not specified above (e.g. private passenger cars and freight transport).

In the study, fuel consumption data from public transportation are provided by the company that manages the service in Licata municipality, while data on municipal fleet are provided by the Licata Municipal traffic warden office.

The amount of fuel consumed by private and commercial transport is not available; it is instead calculated considering annual kilometres travelled per vehicle and an efficiency factor of fuel-per-distance (litres per km) (IPCC, 2006).

In detail, the amount of fuel consumed by vehicle type i and fuel type j can be estimated with the following equation:

$$\text{Estimated Fuel} = \sum_{i,j}\left[\text{Vehicles}_{i,j} \cdot \text{Distance}_{i,j} \cdot \text{Consumption}_{i,j}\right] \quad (1)$$

where

Estimated Fuel = amount of fuel consumed estimated from distance travelled data;

Vehicles i,j = number of vehicles of type i and using fuel j;

Distance i,j = annual kilometres travelled per vehicle of type i and using fuel j (km);

Consumption i,j = average fuel consumption (l/km) by vehicles of type i and using fuel j;

i = vehicle type (e.g., car, bus).

j = fuel type (e.g. motor gasoline, diesel, natural gas, Liquefied Petroleum Gas (LPG));

Detailed statistics on the private and commercial transport sector are obtained from A.C·I. (Italian Automobile club) (A.C.I., 2017). In detail, A.C.I. provides statistical data on the vehicle fleet in Licata per vehicle category and fuel type.

Data on average distance travelled and average fuel consumption per km and per vehicle category are obtained, respectively, from Ntziachristos et al. (2008) and European Environment Agency (EEA (2016).

4.2.2. Second step: final energy consumptions inventory

In the second step, authors calculate the final energy consumption inventory. The net calorific values used to convert the data on fuel consumption from mass to energy units are provided by the IPCC (2006).

Table 1
Total land area by use (ISTAT, 2017).

Arable land	Vine	Permanent crops	Kitchen garden	Permanent pasture	Arboriculture and woods	Unutilised agricultural area and other land
7117	1103	867	7	211	151	820

4.2.3. Third step: BEI compilation

Based on the energy consumption, the related CO_2/CO_{2eq} emissions are calculated, according to the Tier 1 method of the IPCC (2006), with the following equation:

$$\text{Emission} = \sum_{f} [\text{Fuel}_f \cdot \text{EF}_f] \quad (2)$$

where.

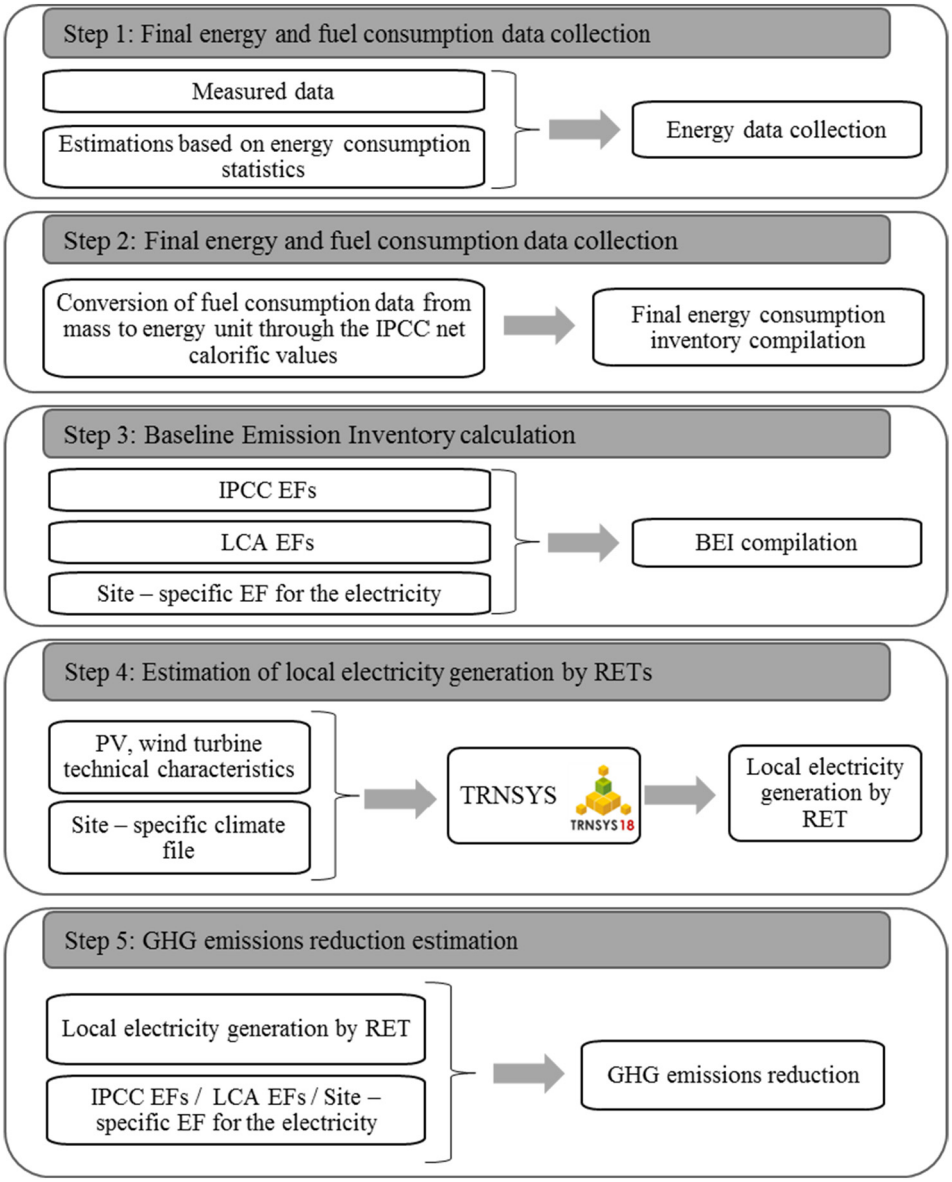
Emission = emissions of CO_2/CO_{2eq} (kg);
$Fuel_f$ = estimated fuel consumption (TJ);
EF_f = emission factor (kg/TJ) (Table 3);
f = type of fuel (e.g. petrol, diesel, natural gas, LPG, etc.).

The BEI is compiled using both the IPCC and the LCA approaches. As previously stated, in the LCA (II) approach the CO_{2eq} emissions related to electricity consumption are calculated considering the specific electricity mix generation of Sicily (TERNA, 2010). In detail, authors assess the percentage composition of 1 MWh of electricity generated in Sicily in 2010 per type of power plant and fuel and calculate the GHG EF using the following equation:

$$EF_{Electricity} = \sum El_{p,f} \cdot EF_{p,f} \quad (3)$$

where

$EF_{Electricity}$ = GHG EF referred to the Sicilian electricity mix (tCO_{2eq}/MWh);
$El_{p,f}$ = contribution of each power plant to the generation of 1 MWh of electricity (MWh);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GHG emissions reduction

Fig. 4. Energy and GHG balances: a step-by-step procedure.

Table 2
Data collection on the final energy consumption.

Sector	Description	Data source
Municipal buildings, equipment/facilities and tertiary (non-municipal) buildings, equipment/facilities	Final energy consumptions related to lighting, heating, air conditioning and ventilation (electrical equipment) in municipal building and public building (school, theatre, etc.), also energy consumption in water and waste management facilities	Financial accounting ledger of Licata Municipal of 2010
Public lighting	Final energy consumption related to public lighting owned or operated by the local authority (e.g. street lighting and traffic lights)	Electricity bill available in the Licata Municipal
Residential buildings	Final energy consumption from residential buildings	Electricity: own estimation based on statistic energy consumption indicator Natural gas: natural gas data consumption provided by the supply company
Agriculture	Final energy consumption in buildings, facilities and machinery in the primary sector (agriculture, forestry and fisheries)	Regional Sicilian Department of Agriculture and Forestry
Transport	Final energy consumption in all road transportation on the street network that is in the competence of the local authority (energy consumption from municipal fleet, public transport, private and commercial transportation)	Public transport: company that provide the service in Licata municipality Municipal fleet: Licata Municipal traffic warden office Private and commercial transport: own estimation based on statistic energy consumption indicator

$EF_{p,f}$ = emission factor per type of plant and fuel (tCO_{2eq}/MWh).
p = type of power plant (wind, thermal power plant, etc.);
f = type of energy sources (wind, coal, oil, etc.)
The utilised EFs are recapped in Table 3.

4.2.4. Fourth step: estimation of local electricity production by RETs

In order to assess the impact of the electricity generated by RETs in reducing GHG emissions, two actions are hypothesized to be implemented in the municipality. In detail, the first action consists in the installation of photovoltaic (PV) systems on public buildings (Ortega, 2012). For this scope, 11 public buildings that are suitable for the PV installation, with a total surface available of 4416 m^2 are identified. The electricity produced by PV is estimated assuming the installation of polycrystalline solar modules with a nominal power of 250 W_p and an area equal to 1.5 m^2 (Europe Solar Production, 2017).

The electrical power available from the installed PV devices is simulated through TRNSYS software (Type 194) (Klein, 2010). In detail, TRNSYS simulates the energy production from PV through the five - parameters model (light current (I_L), the diode reverse saturation current (I_o), the series resistance (R_s), the shunt resistance (R_{sh}), and the modified ideal factor (a)) (Fry, 1999) based on the current-voltage relationship (Eq. 4). The five parameters depend on the local weather condition and PV panel characteristics:

$$I = I_L - I_o\left[e^{\frac{V+IR_s}{a}} - 1\right] - \frac{V + IR_s}{R_{sh}} \quad (4)$$

where:

$$a = \frac{N_s n_1 k T_c}{q} \quad (5)$$

The electron charge q, and Boltzmann's constant k are known, n_1 is the usual ideal factor, N_s is the number of cells in series and T_c is the cell temperature. The power produced by the PV device is the product of the current and voltage.

The second action consists in the installation of 1000 kW of small wind turbines (the rated power of the single turbine is 3 kW) in the residential sector (Aeolos, 2017)). The power output of the wind turbines is simulated by TRNSYS through the following equation (Type 90) (Eq. (6)):

$$P = C_P \rho A_R U_0^3 \quad (6)$$

where
C_p = power coefficient for a wind turbine.
ρ = air density;
A_R = area of the rotor;
U_0 = velocity in the free stream.

4.2.5. Fifth step – GHG emissions reduction estimation

Based on the local electricity generation estimated in the Step 4, authors assess the achievable CO_2/CO_{2eq} emissions reduction through the IPCC, LCA (I) and LCA (II) approaches.

5. Results and discussion

5.1. Final energy consumption

The total final energy consumption of the Licata municipality in 2010 is estimated to be 407,318 MWh (Table 4).

With reference to the transport sector, Table 5 reports the data collected on public transports and on the municipal fleet, while Table 6 shows data on Licata private and commercial transport classified by category and fuel type.

The private and commercial transport is responsible for the highest consumption with a share of 74% of the overall final energy consumption.

With reference to the type of fuel, private and commercial transport represents 100% of the overall LPG consumption, 94% of the overall diesel consumption, and 98% the overall gasoline consumption. The municipal fleet and public transport sector cause less than 1% of the overall final energy consumption.

The residential building sector represents a share of 20% of the overall final energy consumption. This sector is responsible for the highest consumption of electricity (84%) and of natural gas (98%). The residential electricity consumption per capita is equal to 1271 kWh/year in 2010 (ISTAT, 2010), and the total electricity consumption, obtained multiplying this value by the number of inhabitants (39,082 in 2010) is showed in Table 6.

The municipal and public buildings (municipal building, schools, police station, traffic police stations, museum, etc.) are responsible for 0.7% of the overall energy consumption. In detail, the 54 municipal buildings are responsible for 2% of the electricity and natural gas consumption.

Table 3
EFs of the IPCC and LCA approaches.

Emission factors	IPCC (tCO_2/MWh)	LCA (I) (tCO_{2eq}/MWh)	LCA (II) (tCO_{2eq}/MWh)
EF_{Diesel}	0.267	0.305	0.305
$EF_{Gasoline}$	0.249	0.299	0.299
EF_{LPG}	0.227	0.282	0.282
$EF_{Natural\ ga}$	0.202	0.237	0.237
$EF_{Electricity}$	0.483	0.708	0.656

Table 4
Final energy consumption (MWh).

Sector	Electricity	Natural gas	LPG	Diesel	Gasoline	Total
Buildings						
Municipal buildings, equipment/facilities	1390	728				2118
Tertiary (non-municipal) buildings, equipment/facilities	660					660
Residential buildings	49,673	31,208				80,881
Public lighting	7183					7183
Others: agriculture/forestry/fisheries	539			9609	2306	12,454
Transports						
Municipal fleet				110	106	216
Public transport				2233		2233
Private and commercial transport			4352	184,955	112,265	301,572
Total	59,445	31,936	4352	196,907	114,677	407,317

Table 5
Data on Licata public transport and municipal fleet in 2010.

Typology	Buses	Passengers car	Light commercial trucks	Heavy-duty vehicles	Motor cycles
Public transport	9 (D[a])				
Municipal fleet		31 (18 G[b] + 13D)	1 (D)	2 (D)	17 (G)

[a] D = diesel.
[b] G = gasoline.

The tertiary (non-municipal) buildings, equipment/facilities represent 0.2% of the overall consumption and 1% of the electricity consumption.

The electricity consumption for public lighting represents 2% of the overall final energy consumption, and 12% of the total electricity consumption.

The agriculture/forestry/fisheries sector is responsible for 5% of diesel consumption, 2% of gasoline and 1% of electricity.

Considering the fuel type, the highest consumption is diesel with a share of 48%, followed by gasoline, electricity and natural gas with shares of 28%, 15% and 8%, respectively. The LPG represents 1% of the overall fuel consumption.

5.2. CO_2/CO_{2eq} emissions inventory

The related CO_2/CO_{2eq} emissions are equal to 117,278 tCO_2 (Table 7) in the IPCC approach, to 145,228 tCO_{2eq} (Table 8) in the LCA (I) approach and to 142,166 tCO_{2eq} (Table 9) in the LCA (II) approach. Fig. 5 shows the CO_2/CO_{2eq} emissions per capita.

The private and commercial transport represents the highest CO_2/CO_{2eq} emissions sector with a share of 66.8% in the IPCC approach, of 62.8% in the LCA (I) and of 64.2% in the LCA (II) on the total emissions. The residential building sector follows with a percentage contribution of 25.8% in the IPCC approach, 29.3% in the LCA (I) and 28.1% in the LCA (II).

The agriculture/forestry/fisheries and the public lighting sectors are responsible, respectively, for 2.9% and 3% of the total CO_2 emissions in the IPCC approach. They represent, respectively, 3.5% and 2.8% of the total CO_{2eq} emissions in the LCA (I) approach and 3.3% and 2.8% in the LCA (II).

The municipal and public buildings represent 0.7% of the overall emissions in the IPCC approach and 0.8% in both the LCA (I) and LCA (II) approaches.

Table 6
Data on Licata private and commercial transport in 2010 (Own elaboration from data A.C.I.)

Vehicle category	Gasoline	Diesel	LPG
Heavy and light duty vehicles (−)	810	2758	11
Passenger cars (−)	11,920	7637	287
Motor cycles (−)	3306	3	–

The tertiary (non-municipal) buildings, equipment/facilities and the public transport are responsible, respectively, for 0.3% and 0.5% of the overall emissions in all the considered approaches.

With reference to the emissions from each type of fuel, the diesel consumption is responsible for the highest CO_2/CO_{2eq} emissions equal to 45% in the IPCC approach, and to 41% and 42% in the LCA (I) and LCA (II) approaches, respectively. The electricity consumption follows with a percentage contribution of 24% in the IPCC approach, 29% in the LCA (I) and 27% in the LCA (II). Diesel, natural gas and LPG consumptions are responsible, respectively, for 24%, 5% and 1% of the overall emissions in all the examined approaches. In the results achieved by the LCA approaches the share of the electricity on the total emissions is higher if compared to IPCC approach.

The comparison of the obtained results shows that the percentage variations between the emission values obtained with the LCA (I) and the LCA (II) approaches in comparison to the IPCC approach are equal to 24% and 21%, respectively. The increase in the estimated emissions in the LCA approaches is mainly related to the emissions from the electricity consumption. These percentage variations are quite relevant and are mainly due to the different system boundaries that characterize the approaches; moreover, the IPCC approach accounts only the CO_2 emissions, while in both LCA approaches all GHGs are taken into account.

The LCA approach, is accounting the CO_{2eq} emissions related to the whole life cycle of each energy carrier. The LCA approach can provide a more realistic GHG estimation than the IPCC approach especially when the RESs and the emissions related to non-energy sectors have a relevant weight in the energy balance, in fact in both cases the upstream and downstream emissions could have impacts higher than those in the use-phase.

The comparison among the three approaches with regard to emissions by fuel shows that the emissions from electricity sector in LCA (I) and LCA (II) approaches are higher than the emissions calculated with the IPCC approach by 47% and 36%, respectively. The differences are lower in the cases of fossil fuels: 24% for LPG, 20% for gasoline, 17% for natural gas and 14% for diesel emissions.

With regard to the GHG EF related to the electricity generation mix, the use of specific EF for the Sicilian electricity mix generation entails a reduction of emissions of about 7% if compared to those calculated using the Italian electricity LCA EF provided by ELCD. The differences can be

Table 7
CO_2 emissions – IPCC EFs (tCO_2).

IPCC - CO_2 emissions (tCO_2)						
Sector	Electricity[a]	Natural gas	LPG	Diesel	Gasoline	Total
Buildings						
Municipal buildings, equipment/facilities	671	147				818
Tertiary (non-municipal) buildings, equipment/facilities	319					319
Residential buildings	23,992	6304				30,296
Public lighting	3469					3469
Others: Agriculture/Forestry/Fisheries	260			2566	574	3400
Transports						
Municipal fleet				29	26	56
Public transport				596		596
Private and commercial transport			988	49,383	27,954	78,325
Total	28,711	6451	988	52,574	28,554	117,278

[a] Calculated using the Italian IPCC CO_2 EF for consumed electricity.

Table 8
CO_{2eq} emissions – ELCD EFs, LCA (I) (tCO_{2eq}).

LCA (I) - CO_{2eq} emissions (tCO_{2eq})						
Sector	Electricity[a]	Natural gas	LPG	Diesel	Gasoline	Total
Buildings						
Municipal buildings, equipment/facilities	984	172				1156
Tertiary (non-municipal) buildings, equipment/facilities	467					467
Residential buildings	35,169	7396				42,565
Public lighting	5086					5086
Others: Agriculture/Forestry/Fisheries	382			2931	690	4003
Transports						
Municipal fleet				33	32	65
Public transport				681		681
Private and commercial transport			1227	56,411	33,567	91,205
Total	42,088	7568	1227	60,056	34,289	145,228

[a] Calculated using the Italian LCA CO_{2eq} EF for consumed electricity.

Table 9
CO_{2eq} emissions – ELCD EFs for fossil fuels and specific emission factor for Sicilian electricity mix generation, LCA (II) (tCO_{2eq}).

LCA (II) - CO_{2eq} emissions (tCO_{2eq})						
Sector	Electricity[a]	Natural gas	LPG	Diesel	Gasoline	Total
Buildings						
Municipal buildings, equipment/facilities	913	172				1085
Tertiary (non-municipal) buildings, equipment/facilities	433	0				433
Residential buildings	32,610	7396				40,006
Public lighting	4716	0				4716
Others: Agriculture/Forestry/Fisheries	354	0		2931	690	3974
Transports						
Municipal fleet				33	32	65
Public transport				681		681
Private and commercial transport			1227	56,411	33,567	91,205
Total	39,026	7568	1227	60,056	34,289	142,166

[a] Calculated using the Sicilian LCA CO_{2eq} EF for consumed electricity.

higher in the case of municipalities with a high share of electricity on overall consumptions. Then, the adoption of site-specific LCA EF for the electricity consumption is recommended if the weight of the electricity in the overall energy consumption is not negligible or if there are significant differences between the regional and the national electricity mix production.

In order to fulfil the requirements of the CoM, Licata has to reduce its emissions by 2020 by 23,456 tCO_2 in the IPCC approach, 29,046 tCO_{2eq} in the LCA (I) approach and 28,433 tCO_{2eq} in the LCA (II) approach. The low-carbon strategies should be mainly implemented in the private and commercial transport and in residential sectors.

5.3. Local electricity generation from RETs and expected CO_2/CO_{2eq} emissions reduction

Table 10 shows the estimated local electricity generation from the PV modules and the wind turbines. The total electricity generated results equal to 2608 MWh/year, of which 60% from wind turbines and 40% from PV modules.

Figs. 6 and 7 show, respectively, the power generated (MW) in 1 year by the simulated wind turbines and PV modules.

Table 11 illustrates the GHG emissions reduction achievable with the examined energy strategies in the electricity sector. The obtained GHG emissions reduction represents a percentage of the total reduction

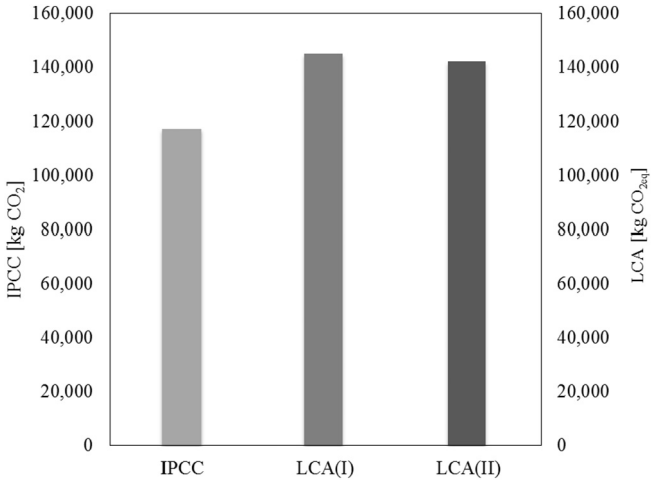

Fig. 5. CO_2/CO_{2eq} emissions per capita (IPCC/LCA approach).

required by the CoM equal to 7.2% in the IPCC approach, 7.7% in the LCA (I) and 7.4% in the LCA (II).

With reference to the PV modules installation, the GHG emissions reduction by m^2 of roof of public building is about 0.13 tCO_{2eq}/m^2. This result can be a support for an ex ante evaluation of the GHG emissions reduction achievable with PV systems installation in municipalities with climatic characteristics similar to Licata, thus a large part of insular and peninsular Mediterranean area.

6. Conclusions

To endorse and support the local authorities in matching their GHG reduction goal, the European Commission launched the CoM initiative.

In this context, authors develop a final energy consumption balance and a GHG inventory of a small municipality in Italy. They apply both the IPCC and the LCA EFs to estimate the CO_{2eq}/CO_2 emissions. Further, they use a third approach in which fossil fuels EFs are based on the ELCD but the electricity GHG EF is calculated considering the Sicilian - specific electricity mix. Moreover, they analyse two energy strategies in order to evaluate the achievable GHG emissions reduction.

The analysis shows that the compilation of the BEI, at local level, can suffer from the lack of information associated to the final energy consumption in many economic sectors. This problem is commonly recognized in most of small municipalities that usually do not have an energy consumption monitoring system. Missing data can be filled by using statistical energy data; in this context, the paper provides a methodology to fill the data gap. However, it is important to outline that the use of statistical data and parameters increases the uncertainty of the analysis so it is useful the implementation in each municipality of an energy monitoring system in order to obtain reliable results to be used in the SEAP and to assess the effectiveness of the implemented climate strategies.

The applied methodology provides a measure of the magnitude of the differences in the CO_{2eq}/CO_2 emissions estimations carried out through the IPCC and the LCA approaches. The comparison highlights that the difference in the obtained results can be significant. Considering the importance of climate change and the key role of cities, authors recommend the LCA approach as it provides a more complete assessment of the GHG emissions. The LCA approach includes the upstream and the downstream supply chains of the energy sources therefore, it is more suitable than the IPCC approach in order to identify more effective energy strategies to reduce both the local and global GHG emissions and match the target set by the European Union.

The comparison between the GHG emissions of the specific Sicilian electricity mix and the Italian average one highlights that the difference in the results are not marginal. Then, the adoption of site-specific LCA EF for the electricity consumption is recommended especially in the perspective of the increase in the electricity share on the overall energy consumption, due to the electrification of final energy consumption (e.g. in the transportation and building sectors).

With reference to the examined energy strategies, the obtained GHG emissions reductions represent a small percentage of the total reduction required by the CoM. Then, these results confirm that it is of paramount importance to carry out an ex ante evaluation of the proposed actions in order to assess the achievable GHG emissions reduction and to obtain reliable information for the allocation of the available financial resources to the environmental policies.

The obtained results can provide a useful methodological indication for decision makers/local authorities involved in the CoM initiative and in the assessment of the environmental burdens associated to the energy consumptions of cities and the benefits achievable with the implementation of specific energy strategies.

This work can be a starting point for a close collaboration between research centres and municipal authorities in the perspective of a more sustainable development of cities. In this context, future work could be developed in the assessment of the eco – profiles of electricity consumed at local scale in order to obtain more reliable data about the related environmental impacts with particular emphasis on the GHG emissions. With references to the local energy strategies, in order to

Table 10
Simulated local electricity generation from the PV modules and the wind turbines devices.

Sector	Measures	Total installed capacity (kW)	Technology	Electricity generated (MWh/year)
Public buildings	PV power plants	736	Polycrystalline PV module, 250 W_p	1036
Residential buildings	Wind power plants	1000	Wind turbine, 3 kW_p	1571

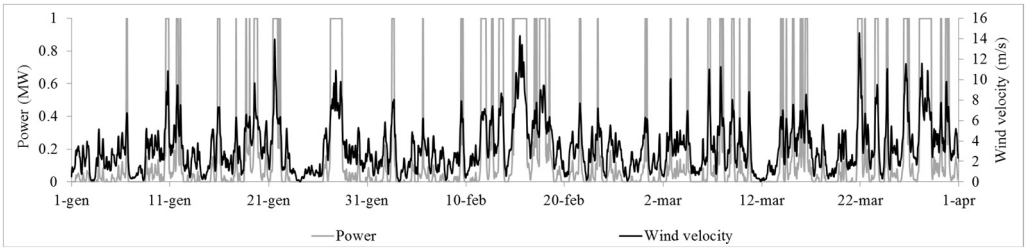

Fig. 6. Power generated with the simulated wind turbines.

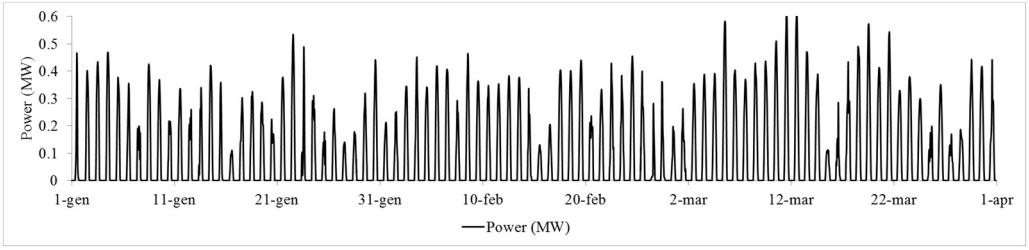

Fig. 7. Power generated with the simulated PV modules.

Table 11
GHG emissions reduction achievable with the examined energy strategies.

GHG emissions from the electricity final consumption	IPCC (tCO_2)	LCA (I) (tCO_{2eq})	LCA (II) (tCO_{2eq})
Electricity emissions before the RET installation	28,712	42,087	39,025
Electricity emissions after the RET installation	27,452	40,323	37,395
GHG emissions reduction - PV	501	663	609
GHG emissions reduction - Wind	759	1102	1021

provide the local authorities with simplified tools to evaluate the effectiveness of the actions, future work could involve the definition of simplified LCA based indicators, like site specific GHG emissions reduction (e.g. GHG emissions reduction per unit area of PV system/roof) for different renewable energy technologies or other kind of energy strategies.

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